Covariate Risk, Index Insurance, and the Sustainability of Informal Risk Sharing Arrangements

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Abstract

We examine how systemic risk affects the sustainability and value of informal risk sharing agreements among the poor in developing countries. To this end, we develop a stochastic dynamic game model in which two agents enter into an income risk sharing arrangement that calls for income to be transferred from the member who has the higher income to the member who has the lower income. We derive the Markov sub-game perfect equilibrium by numerically solving the group members' interrelated Bellman equations. Simulations confirm that informal risk sharing arrangements become increasingly difficult to sustain when systemic shocks become more frequent and severe. We observe a critical level of correlation between the incomes of the risk-sharing agents beyond which the arrangements quickly become unsustainable due to strong incentives for the higher income agent to default on her obligations. We then introduce index insurance into our model and analyze how access index insurance against covariate shocks improves agents' incentives to remain in the informal risk sharing arrangement when adverse systemic shocks occurs. We find that index insurance may, or may not, improve the sustainability of risk-sharing arrangements, depending mostly on the premiums charged for the insurance coverage and the extent of basis risk.

Keywords: Informal risk-sharing, limited commitment, index insurance, stochastic dynamic games.

JEL Codes: C63, D81

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1 Introduction

People in developing countries lack access to formal financial services such as savings, loans, and insurance. Researchers have found that these people turn to informal-risk sharing channels to smooth income variations, which, in turn, smooth consumption variation and improve welfare.[2] An example of informal risk sharing is income transfer behavior among groups of people. Suppose income shocks are independently distributed among members of an informal risk sharing group; one member's experience of adverse income shock is independent of the adverse income shock experienced by the others. If one member of this group experiences an income loss during the current period, then he or she will turn to the members of his or her group for financial assistance. It is implicitly agreed that during future periods, the member who previously enjoyed financial assistance from others will help other group members who experience income losses. The beneficiaries during the current period are not necessarily those who were benefactors during previous periods. Instead, the beneficiaries are determined by the realization of income shocks. The informal risk sharing group must be sustainable to be of value to participating members. The financial needs of beneficiaries and the availability of financial assistance from benefactors must be in balance during each period so that the informal risk sharing can continue. Because there is no formal enforcement of the implicitly agreed transfers, the informal risk sharing is subject to falling apart if one or more members are unable to honor their obligations.

In the literature there is an abundant theoretical analysis of how informal risk sharing performs (Coate & Ravallion, 1993; Dercon, 2002; Dubois, Jullien, & Magnac, 2008; Kocherlakota, 1996). Like formal insurance, informal insurance provided by a group is subject to information asymmetry because the individual effort to manage income risks ex-ante is private information. Some studies assume that the commitment is binding and investigate how information asymmetry affects the efficient equilibrium, resulting in either moral hazard or adverse selection. Others assume that the information is symmetric and investigate how limited commitment causes the equilibrium deviating from the first-best scenario. However, the current literature mainly focuses on insuring against idiosyncratic risks—that is, risks that are independently distributed. Few studies have formally explored how the presence of aggregate level risks (i.e., correlated risks) affects the performance of informal risk sharing. It is not certain whether the presence of aggregate level risks will exacerbate the issues of information asymmetry and/or limited commitment. Udry (1994) posits that the contingent repayment of loans functions as a risk sharing tool because the loan is reduced or exempt by the lender when the borrower experiences an income loss. Consider that if an aggregate level shock occurs, it is difficult to know whether the repayment will be reduced or exempt because the lender also experiences income losses. As noted by Dercon, De Weerdt, Bold, and Pankhurst (2006), "Even in [this] relatively high information environment, the

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[2] Many empirical analyses have found imperfect risk diversification. De Weerdt and Dercon (2006) find that informal risk sharing occurs not only at village level, but at the network level, too. Fafchamps and Lund (2003) find that informal risk sharing exists among friends and relative networks rather than at the village level. Besley, Coate, and Loury (1993) investigate rotating savings and credit associations (Roscas) that villagers form to expedite the purchase of lumpy goods. Mark R. Rosenzweig and Stark (1989) state that marital arrangements in India can be viewed as implicit risk sharing contracts that deal with spatially-covariant risks. Munshi and Rosenzweig (2006) find that the lack of formal insurance in urban places and access to informal risk sharing in rural places mitigate into-urban migration incentives, which results in a persistent urban-rural wage gap.

type of risk handled is restricted, focusing on non-covariate and relatively infrequent risks. Other products may not be easily offered unless solutions for monitoring and sustainability are found. Strengthening indigenous risk sharing arrangements should be an important part of general social protection policies." We provide three reasons why aggregate risks are relevant to informal risk sharing arrangements.

First, people in developing countries are highly subject to aggregate shocks. Most of them make their livelihood through agricultural production, which is affected by aggregate factors, such as rainfall, temperature, and market conditions. Dubois et al. (2008) show that a village dummy variable (which captures village-level aggregate shock) could explain 24 percent of consumption variance, whereas the explanatory power that limited commitment and formal contracts provide is low. For example, the HIV/AIDS crisis, which causes high mortality rates, puts pressure on funeral groups in Ethiopia and Tanzania, where groups insure against funeral costs (Dercon et al., 2006).

Second, group formation theory suggests that in a process known as positive assertive matching, people tend to form groups with others who have similar characteristics (geographical distance, occupation, earnings, wealth, religion, etc.), which means that income distributions are correlated within the group. Theoretically, it is optimal to form risk sharing groups with people who possess negatively-correlated income streams with themselves, which ensures that their income variations are perfectly smoothed. However, empirical evidence shows that the group that people can form is constrained by the extent and the form of social networks around them (Fafchamps & Gubert, 2007). Another type of the positive assertive matching is based on income autocorrelation. With highly autocorrelated income streams, a person's income depends highly on income realization during the last period. Xing (2015) explains that because a person with highly autocorrelated income streams probably needs a transfer from others for consecutive periods, the incentive constraint of not deviating from the obligation becomes tighter for his or her group members because they must make several rounds of transfers before they can enjoy the benefits of this risk sharing arrangement. Thus, people with lowly correlated income streams prefer partnering with lowly correlated income streams rather than with highly correlated income streams.

Third, smaller groups are more abundant when there are aggregate shocks because in larger groups, the probability that the group will be affected by aggregate level shocks is reduced. A village-level shock is no longer an aggregate shock if risk sharing happens at a level broader than the village. Nonetheless, Genicot and Ray (2003) state that the size of stable groups is restricted by the requirement that the informal risk sharing group must be immune to deviating by both individuals and sub-groups.

Our study is the first to investigate how the presence of aggregate risks affects the sustainability of informal risk sharing. We focus mainly on the aspect of limited commitment and, thus, we assume that information is symmetric. The goal of this paper is not to provide evidence that information is symmetric; rather our objective is to determine how limited commitment is affected by aggregate shock alone, without the complications brought about by information asymmetry. In this paper, we define informal risk sharing as all kinds of income transfer behavior among people. It can consist of purely informal bilateral relationships, or it can consist of "semi-informal" arrangements wherein a group of people form multilaterally beneficial relationships and act according to a long-established rule, without the presence of enforcement. In this paper, we distinguish informal from formal risk sharing on the basis of whether enforcement is limited (informal) or full (formal).

We set up a dynamic stochastic game in which two persons interact in an infinite time horizon. We first examine the deviating decision that occurs when incomes are independently distributed. Then we look at the deviating decision that occurs when incomes are correlated. We find that in the case of aggregate shocks, the net value of informal risk sharing decreases and the incentive to deviate rises dramatically. Limited commitment constrains the optimal risk sharing arrangement (Foster & Rosenzweig, 2001). Our results show that with aggregate shocks, limited commitment further constrains the risk sharing arrangement because it makes deviating more appealing. We then consider three types of index insurance and study how the access to indemnity insurance can mitigate the negative effects of aggregate shock. We find that only when index insurance indemnity is available to all participants in the informal risk sharing arrangement for extended periods of time will access to index insurance indemnity improve the sustainability of the informal risk sharing arrangement and reduce participants' incentives to deviate. If the insurance is only available to one agent, the agent opts out of the informal risk sharing arrangement.

This paper is organized as follows: section 1.2 provides a literature review of the existing theoretical models of informal risk sharing, with a particular focus on how the deviating behavior is modelled; section 1.3 introduces our model set-up of an informal risk sharing arrangement in which two agents agree to share risks with a limited commitment; section 1.4 presents the simulation results of the model and compares the equilibrium results with and without the presence of aggregate shocks; section 1.5 provides sensitivity analysis with regards to model parameters; section 1.6 concludes.

2 Literature Review

The existing theoretical analysis about informal risk sharing groups can be loosely divided into two strands. The first strand assumes information symmetry and investigates how the lack of enforcement tools affects the equilibrium outcome (Coate & Ravallion, 1993; Kocherlakota, 1996; Ligon, 1998); the second strand assumes full commitment and discusses how information asymmetry makes the second best deviate from the first best (Barr, 2003; Jain, 2015). This dissertation focuses on the first strand and assumes information symmetry. In village economies, people dwell in the same area, and their interaction with one another reduces transaction costs down to the minimal level. Consequently, the complete information assumption can be reasonably assumed. We mainly focus on the deviating behavior that is associated with a lack of enforcement tools and a lack of commitment devices. We find three existing theories that explain the agents' motivation to deviate in informal risk sharing groups.

2.1 Self-Enforcing Implicit Contract Theory

The implicit informal risk sharing arrangement must be self-enforcing. That is, people must be willing to stay in the arrangement and forgo the immediate monetary gain that comes from deviating, and they remain in this arrangement not through altruistic preference but because the future benefits of staying in this arrangement outweigh the gains that could be made if they deviated during the current period (Zeller, 1998). The concept of self-enforcing was first discussed by Thomas and Worrall (1988), who investigate a wage contract between a risk-averse worker and a risk-neutral firm. Signing a wage contract will protect both the worker and the firm from wage variations in the spot wage market, but either party could have an incentive to deviate from the wage contract if the wage at the spot market changes in the favor of one party or the other. To characterize the self-enforcing wage contract, the authors use a simple history-dependent updating rule so that both agents have no incentives to deviate. Coate and Ravallion (1993) apply the idea of the self-enforcing contract to informal income transfers between agents in a repeated non-cooperative game, in which incomes are stationary, and equilibrium transfers are history-independent. The solution of transferring non-stationary incomes in an informal risk sharing game is provided by Ligon, Thomas, and Worrall (2000).

Kocherlakota (1996) show that the constrained equilibrium of informal risk sharing characterizes imperfect consumption diversification. This is so because if the income-transfer arrangement is to be self-enforcing, the arrangement must promise the agent who has the higher income during the current period that he or she will have higher future consumption (utility) in the future, which ensures that the agent will be willing to contribute during the current period. The result is imperfect consumption diversification. Genicot and Ray (2003), who extend the scope of self-enforcing, require that the arrangement must be immune to not only individuals but also subgroups. Their model predicts that the size of a group is bounded by the *i*-stability requirement.

2.2 Balanced-Reciprocity Theory

Platteau (1997) finds that Boat Club members withdraw from their informal mutual insurance group in a manner that is inconsistent with the predictions provided by self-enforcing theory. Whereas self-enforcing theory is forward looking, Platteau states that a fisherman decides whether to stay in the group based on history. If the fisherman keeps contributing to his or her group without receiving any benefits (due to positive autocorrelated income), then he or she will withdraw from this group, irrespective of the expected future utility gain if he or she remained in the group. That is, the decision is based on a philosophy of balanced reciprocity. Agents expect the favor will be returned in equal amount soon after they contribute to the group.

2.3 Regret Theory

The third category of the theory is regret theory mentioned by Platteau (1997). It is similar to the time-inconsistency theory. If people have a time-inconsistent preference when they are asked to make a transfer in a period, they will become unwilling to do so even though previously they thought they were going to keep their promises. Whether or not they are willing to make a transfer depends on the specific time spot and their time-inconsistent preference parameter.

2.4 Comparing Different Theories

Based on the existing theories about informal risk sharing, we can discuss the factors can affect the deviating behavior. For example, according to theory of the self-enforcing contract, a person who discounts the future by a larger rate will be more likely to deviate; whereas according to the theory of balanced reciprocity, the subjective discount rate does not affect the deviating decision.

In another example, the aggregate shock[3], according to the balanced reciprocity theory, will not affect deviating because the occurrence of aggregate shock will not affect the past transfer history. However, this is not the case for self-enforcing contract theory; aggregate shock will affect the current utility and the future utility of staying in the risk sharing arrangement, and this will affect the incentives and disincentives of leaving the informal risk sharing group.

3 Model

Our theoretical model is based on the self-enforcing contract theory by Thomas and Worrall (1988), which is the mainstream economic model of implicit agreement. Suppose that two identical agents live for infinite[4] periods at a location where savings and borrowing are not available. Each agent *i* receives at time *t* an income y_{it} that follows an independent and identical distribution.

Suppose the per-period utility function $\mathrm{u(y)}$ is continuous, strictly increasing, concave, and satisfies $\log_{\mathrm{y}\to\infty} \mathrm{u(y)} = \infty$. The two agents agree to share their incomes at an exogenous risk sharing rate θ. This means that during each period, the agent with the higher income (suppose it is agent *i*) promises to transfer a fraction of their income difference $0.5\theta(\mathrm{y}_i - \mathrm{y}_{-i})$ to the other agent *j*, where $0 < \theta \leq 1$. $\theta = 1$ denotes full risk sharing, because both agents have an equal income after the transfer. $0 < \theta < 1$ denotes partial risk sharing. Because the agreement is made in private between two agents who do not invoke formal contracts, there is no enforcement. The risk sharing arrangement remains operative until one agent deviates from his or her promises—that is, if he or she has a higher income than the other agent during one period yet chooses not to transfer the promised part of the income difference to the other agent. Only the agent who has the higher current income has the privilege to choose whether or not to deviate. The economic consequence of deviating is that both agents will be in autarky during all remaining periods.

Let ρ be the subjective discount rate, $\delta = 1/(1+\rho)$ be the subjective discount factor. Let A be the expected value of staying in autarky; it is the sum of expected utilities during all future periods discounted into the current period, $\mathrm{A} = \sum_{\mathrm{t}=1}^{\infty} \delta^{\mathrm{t}} \mathrm{E}_{\tilde{\mathrm{y}}_{\mathrm{t}}} (\mathrm{u}(\tilde{\mathrm{y}}_{\mathrm{t}}))$. In addition to the financial consequences, assume that if a participant deviates, he or she will (because of the deviating behavior) receive a social penalty γ. That penalty can consist of a social stigma (being despised, resented, and a loss of face) or a loss of social capital (trust).

Let $\mathrm{V}(\tilde{\mathrm{y}}_1, \tilde{\mathrm{y}}_2)$ be the value function of the risk sharing arrangement for person 1, given that their current income levels are $\tilde{\mathrm{y}}_1$ and $\tilde{\mathrm{y}}_2$, respectively. It represents the maximum value accrued to agent 1 for remaining in the risk sharing arrangement during all previous periods until the current period. Agent 1 may or may not deviate during the current period; he or she will choose the option

3 The effect of shocks on the sustainability of the risk sharing arrangement has already been investigated. For example, Udry (1994) shows that a negative shock experienced by the borrower would not necessarily increase the likelihood of deviation. He reasons that the repayment requirement will be reduced by the lender (contingent repayment), and he finds that the tendency to deviate decreases with negative shocks. However, his analysis focuses mainly on idiosyncratic risks.

4 The infinite time horizon assumption becomes more realistic if we conceptualize farmers as comprising households that live over many generations and interact with each other during each generation.

that gives him or her the highest level of $V(\tilde{y}_1, \tilde{y}_2)$. Thus, the optimal choice and V are a function of $\tilde{y}_1$and $\tilde{y}_2$.

Let B be the expected maximum value for agent 1of being in the risk sharing arrangement, discounted by one period. $B = \delta E_{\tilde{y}_1,\tilde{y}_2} V(\tilde{y}_1, \tilde{y}_2)$. B is independent of income levels $\tilde{y}_1$ and $\tilde{y}_2$.

Both B and $A - \gamma$ represent future payoffs; the former is the future payoff of cooperating, the latter is the future payoff of deviating. It is obvious that if $B < A - \gamma$, then the risk sharing arrangement is inviable. Regardless of the income outcomes, the agent who has higher income will always deviate and income sharing will never take place[5]. This is so because by deviating the agent gains in the present and in the future.

If $B > A - \gamma$, then the agent who has the higher income may or may not deviate, depending on the realized income levels of both agents. Take agent, 1 for example. The utility he or she obtains can be categorized into three cases that are given by the value function:

$$V(y_1, y_2) = \begin{cases} u(y_1) + A - \gamma, & \text{if } \ agent\ 1\ deviates \\ u(y_1) + A, & \text{if } \ agent\ 2\ deviates \\ u\big(y_1 + 0.5\theta(y_2 - y_1)\big) + B, & \text{if other } \ cases \end{cases}$$

These three cases represent three alternative scenarios: (1) agent 1 deviates and keeps all of his or her current income, in which case both agents are downgraded into autarky in all future periods and agent 1 receives a social penalty γ; (2) agent 2 deviates, in which case both agents are downgraded into autarky in all future periods and agent 1 does not receive a social penalty; and (3) neither agent deviates, in which case agent 1 receives a difference transfer, $\theta(y_2 - y_1)$ (it can be positive or negative) during the current period and the risk sharing arrangement continues into next period.

We write out the conditions of deviating:

$$V(y_1, y_2) = \begin{cases} u(y_1) + A - \gamma, & \text{if } \ u(y_1) + A - \gamma > u(y_1 + 0.5\theta(y_2 - y_1)) + B \\ u(y_1) + A, & \text{if } \ u(y_2) + A - \gamma > u(y_2 + 0.5\theta(y_1 - y_2)) + B \\ u\big(y_1 + 0.5\theta(y_2 - y_1)\big) + B, & \text{if other} \end{cases}$$

Agent 1 will be indifferent to the choice between deviating and cooperating if and only if $u(y_1) + A - \gamma = u\big(y_1 + 0.5\theta(y_2 - y_1)\big) + B$. In other words, the utility of current income without transfer plus the current value of staying in autarky, when the social penalty is subtracted, is equal to the utility of current income after transfer plus the current value of staying in the risk sharing arrangement. As y_1 and y_2 are not arguments in A and B, given any y_1, we can solve for the critical $y_2^*(y_1) = g(y_1) = y_1 - \frac{2}{\theta}(y_1 - u^{-1}(u(y_1) + A - B - \gamma))$. $g(y_1)$ is well defined if we assume $\log_{y \to 0+} u(y) = -\infty$. Furthermore, $g(y_1)$ has a closed form if we assume that $u(y)$ and its

[5] The only exception occurs when both incomes are equal. However, because we are assuming continuous distributions for the incomes, this is event occurs with probability 0 and can be safely ignored.

inverse $u^{-1}(y)$ have closed forms. Obviously $y_2^*(y_1) = g(y_1) < y_1$[6]. It is easy to determine that if $y_2 < y_2^*(y_1) = g(y_1)$, then agent 1 will deviate; if $y_2 > y_2^*(y_1) = g(y_1)$, then agent 1 will not deviate. Intuitively, when agent 1 has a higher income than agent 2, he or she is willing to honor his or her obligation by transferring the promised money, but only if agent 2's income is high enough to keep the required transfer from rising so high that it destroys agent 1's incentive to keep his or her promises[7]. A sufficient condition for agent 1 never deviating is that $y_2^*(y_1) < 0$ for every y_1.

4 Results

4.1 Baseline Results

Solving the Model

If we know the value of B, then we can determine each agent's decision at every income level and calculate the value function, $V(\tilde{y}_1, \tilde{y}_2|B)$, at each income level. According to the definition, $B = \delta E_{\tilde{y}_1,\tilde{y}_2} V(\tilde{y}_1, \tilde{y}_2|B)$. The value of B can be calculated by root finding of the equation $B - \delta E_{\tilde{y}_1,\tilde{y}_2} V(\tilde{y}_1, \tilde{y}_2|B) = 0$. It can be solved by starting with an initial guess about B and generating a new guess according to an updating rule until convergence. Alternatively, it can be solved using Broyden's method, which is available in the Compecon toolbox developed by Miranda and Fackler (2002).

We started with an initial guess about B, then we solved for $V(y_1, y_2)$ at every value of (y_1, y_2). Then we updated B by $B_{new} = \delta E_{\tilde{y}_1,\tilde{y}_2} V(\tilde{y}_1, \tilde{y}_2|B_{old})$. With the updated B_{new}, we solved for the updated $V(y_1, y_2)$. This iteration continues until B converges. From the contract mapping theorem, a unique solution exists.

Assume $y_{it} = Ye_{it}$. Y denotes the aggregate shock that is common to both agents. Y follows a distribution such that

$$Y = \begin{cases} 1, & \text{with probability } 1 - p \\ 1 - l, & \text{with probability p} \end{cases}$$

l is the amount of loss in an aggregate shock, for example, drought. p is the probability of an aggregate shock event. e_{it} denotes idiosyncratic risks for agent *i*. It follows a log-normal distribution with a mean of $-\sigma^2/2$ and variance of σ^2. Given the loss of drought, *l*, the mean of y_i, *Mean*, the variance of y_i, *Vary*, and the correlation coefficient between agent 1 and agent 2's income, *Corri*, we can determine the probability of drought, p, and the variance of idiosyncratic

[6] Because $A - B - \gamma$ is bounded and assuming $\log_{y\to 0+} u(y) = -\infty$, $u(y)$ is strictly increasing and continuous. Thus, for every value of $u(y_1) + A - B - \gamma$, $u^{-1}(u(y_1) + A - B - \gamma)$ is well-defined (thus, $g(y_1)$is well-defined), and $u^{-1}(u(y_1) + A - B - \gamma) > 0$.

[7] We make the risk sharing game a rigid rule such that either the agent honors his obligation according to pre-specified rule or the agent fails to do so. We do not allow in-between cases where the agent makes a transfer but it is less than the amount promised.

log-income, σ^2 (See Appendix A for details). The following parametrization is used: (1) $\rho = 0.1$, $\delta = 0.91$ (2) *Vary* = 0.075 (3) utility function $u(y) = \frac{1-y^{\alpha}}{1-\alpha}$, $\alpha = 2.5$ (4) $\theta = 0.6$ (5) $\gamma = 0.05$ (6) *Corri*= 0.001 (7) *Mean*= 0.9. We use the qnwlogn routine in the Compecon toolbox to discretize the agent's income distribution.

Starting from an initial guess of $B_0 = A + 20$, we updated B using $B_{new} = \delta E_{\tilde{y}_1,\tilde{y}_2} V(\tilde{y}_1, \tilde{y}_2 | B_{old})$. The convergence criterion is set so that whenever $B_{new} - B_{old} < 10^{-11}$, B is said to be converging. For different potential convergence scenarios, see Appendix B. For a trick that we used to simulate y_{it}, see Appendix C.

Figure 1 shows the fixed-point map. When the updating mapping function is intersected with the 45-degree line, the B value is at its equilibrium value. Using the parametrization above, we find that the expected value of staying at autarky is A= - 9.20 while the expected value of staying at risk sharing arrangement is B = - 8.596. The net value of risk sharing is $B - A + \gamma = 0.65$, which is positive. This result indicates that when all other conditions are held the same, the agent would rather stay in a risk sharing arrangement than stay in autarky.

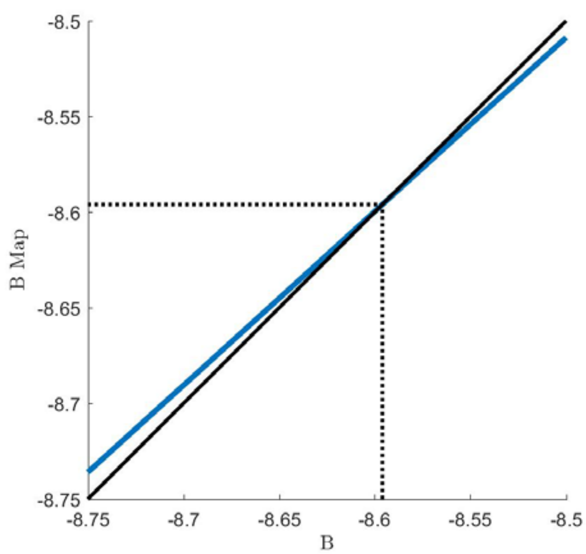


Figure 1: Fixed Point Map - Baseline Case

Deviating Region

Whether the agent deviates during the current period depends on the trade-offs between the current gain from deviating and the future gain that will be secured if the agent stays in the risk sharing arrangement. Figure 2 shows our calculation of the trade-offs and mapping of the optimal decision at each discretized income level for both agent 1 (the horizontal axis) and agent 2 (the vertical axis). The blue shaded area lies below the 45-degree line, indicating that in this region agent 1 has a higher income than agent 2. The boundary of the blue shaded region is the function $g(y_1)$. Since in the shaded region $y_2 < g(y_1)$, agent 1 will always deviate when the income realization of both agents falls into this region. Figure 2 shows that when $y_1 > 0.780$, agent 1 will always choose to honor his or her obligation, regardless of agent 2's income. When $0 < y_1 < 0.78$, agent 1 will not deviate only if $y_2 > g(y_1)$. If agent 2's income falls below the critical value $g(y_1)$, then for agent 1 the current gains from deviating will outweigh the future gains from staying in the risk sharing arrangement, and he or she will deviate. These results are intuitive because they show that agent 1 will always choose to make the transfer whenever his or her own income is sufficiently high (>0.78); if it is not, then he or she will still choose to transfer income as long as agent 2's income is not too low and if the required transfer is not too great.

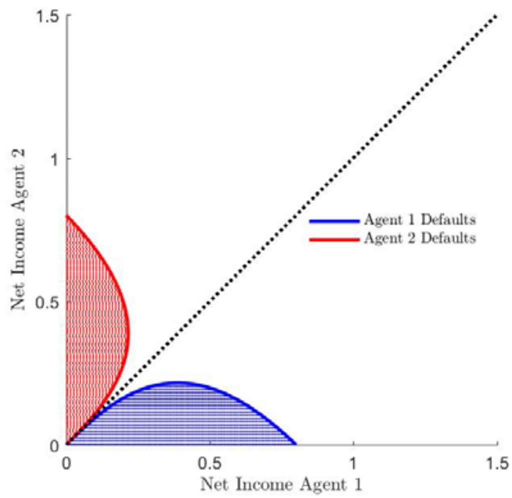


Figure 2: Deviating Region - Baseline Case

To calculate the probability of either agent deviating we calculate the probability that the income levels will fall into the blue- or red-shaded region. That calculation is $\Pr(\text{deviate}) = \int_{-\infty}^{\infty}\int_{0}^{g(y_1)} f(y_1, y_2)dy_2dy_1$=0.000, where $f(y_1, y_2)$ is the bivariate probability distribution function of (y_1, y_2). Although Figure 2 shows a visible deviating region, the probability that incomes will fall into this region is numerically 0. By symmetry, the deviating probability for agent 2 is the same as that for agent 1. With current parametrization, the unconditional probability that either agent will deviate is 0.000. Consequently, the expected number of periods during which the risk sharing arrangement will remain sustainable is infinity.

Value Function

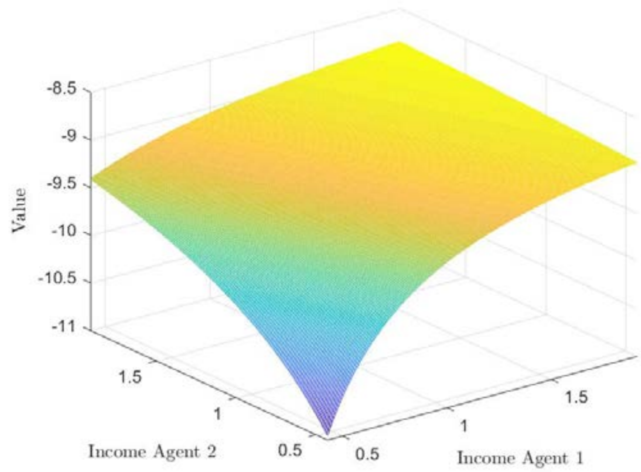


Figure 3: Value Function - Baseline Case

Knowing the expected value of the risk sharing arrangement, we plotted the value function of agent 1 as a function of agent 1 and 2's income in Figure 3. In Figure 4 we show the projected value function (the solid black line) given that agent 2's income is fixed at the mean level $\bar{y}_2$. Thus in Figure 4 the value function is a function of only agent 1's current income. In the same figure, we plot the current value of agent 1 when agent 1 deviates (the green dotted line), agent 2 deviates (the red dotted line), and neither agent deviates (the blue dotted line). The value function should take the maximum of these three when $y_1 > \bar{y}_2$ because when agent 1 has a higher realized income than agent 2, agent 1 must decide whether to deviate. When $y_1 < \bar{y}_2$, agent 2 makes the decision. Agent 2's decision will follow the rule that when $y_1 < g(y_2)$, agent 2 will deviate, but when $y_2 > y_1 > g(y_2)$, agent 2 will not. With the current parametrization, neither agent deviates in the specified income range, as a result the solid black line (which represents the value function) coincides with the blue dotted line (which represents the case neither agent deviates). According to Figure 2, when agent 2's income is fixed at 1, the sufficient condition for agent 1 not to deviate is $y_1 > 0$. As a result, agent 1 will never deviate when $y_2 = 1$, the result of which, is also observed in Figure 3.

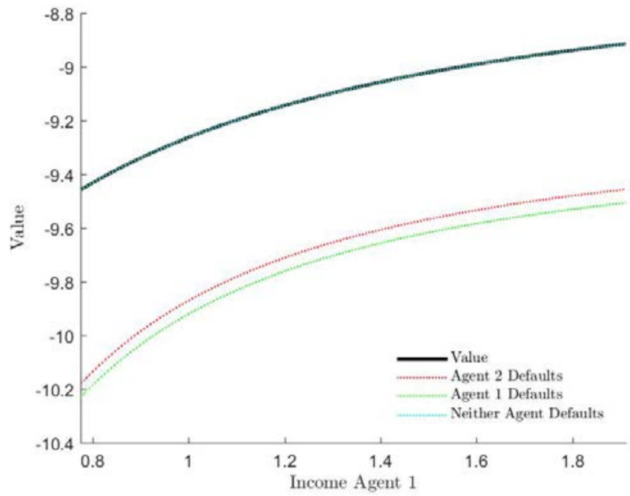


Figure 4: Value Function Projection - Baseline Case

4.2 The Results with Correlated Income

Solving the Model

In this subsection, we present the simulation results when the aggregate shock makes agents' incomes highly correlated. we change only the income correlation coefficient and keep the income mean and income variance the same as in section 1.4.1.1. This allows me to compare our results with results reported in the previous subsection when the aggregate shock is present, but only to the extent that the incomes of the two agents are nearly uncorrelated. For example, we solve the model when *Corri*=0.8. With this parametrization, we find the expected value of staying at autarky is A=-11.882, the expected value of staying at the risk sharing arrangement is B= -11.903, and B < A. The fixed-point map of this case is shown in Figure 5.

Deviating Region

As before, the deviating region is shown in Figure 6. Compared to Figure 2, there is substantially more shaded region. To calculate the probability that either agent will deviate, we calculate the probability that income levels will fall into the blue- or red-shaded region. It is $\Pr(\text{deviating}) = 2\int_{-\infty}^{\infty}\int_{0}^{g(y_1)} f(y_1, y_2)dy_2dy_1 = 0.62$. The expected number of periods during which the risk sharing arrangement will remain sustainable is 1/0.62= 1.61[8].

[8] Suppose an event that lasts for 1 period with probability p, 2 periods with probability p^2, i periods with probability p^i and so on. The expected number of periods it will last is: $\sum_{i=1}^{\infty} i(1-p)^{i-1}p = 1/p$.

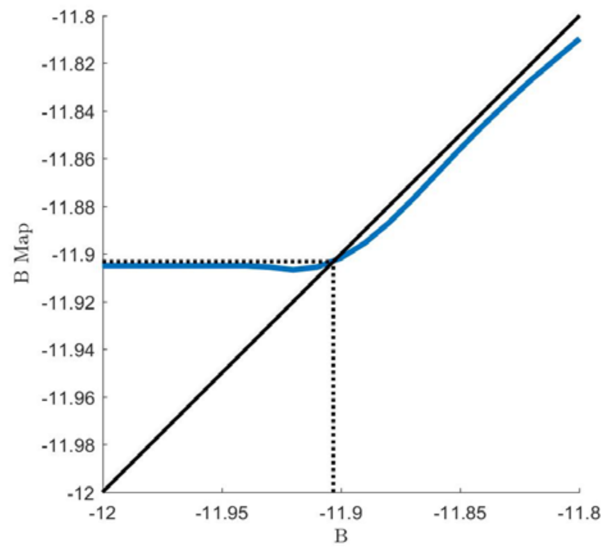


Figure 5: Fixed Point Map - With Correlated Income

Value Function

The unconditional value function is shown in Figure 7. Given that agent 2's income is fixed at the mean level $\bar{y}_2$ (which equals to 1), we plot in Figure 8 the projection of the value function of agent 1. When agent 1 has an income higher than 1.125, agent 1 will deviate, and his or her value function will coincide with the "agent 1 defaults" line; when agent 1 has an income lower than 0.908, it is up to agent 2 to decide whether or not to deviate, and agent 2 actually chooses to deviate; when agent 1 has an in-between income, neither agent will deviate. According to Figure 6, when agent 2's income is fixed at 1, the sufficient condition for agent 1 not to deviate is $y_1 < 1.125$ and the sufficient condition for agent 2 not to deviate is $y_1 > 0.908$, the results of which, are consistent with results observed in Figure 8. Thus, in this case value function has a kink. When agent 1 has an income higher than 1, it is agent 1 who decides whether to deviate. Agent 1 will not deviate if his or her current income is not sufficiently high. According to the agreed risk sharing rule, the transfer that agent 1 has to make is equal in size to $0.5\theta(y_1 - y_2)$ (where θ= 0.6). Agent 1 is willing to make a transfer only if such a transfer is not so big that it will jeopardize his or her incentive to make any transfer at all during the current period. Whenever agent 1 has a sufficiently high income ($> g^{-1}(1)$), agent 1 chooses to deviate.

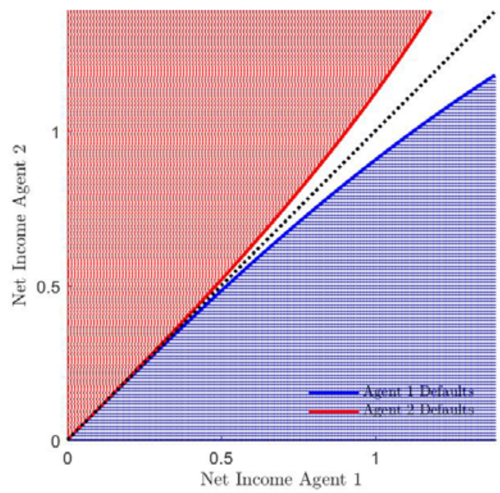


Figure 6: Deviating Region - With Correlated Income

Symmetrically, when agent 1 has an income lower than $\bar{y}_2$, it is agent 2 who decides whether to deviate. Agent 2 will not deviate if agent 1's income is no less than $g(\bar{y}_2)$. This is because agent 2 is willing to make a transfer only if the required transfer is not too large in magnitude to jeopardize his or her incentive to make any transfer in the current period (that is, only if agent 1's income is not below $g(\bar{y}_2)$).

4.3 The Results with Aggregate Shock and Access to Index Insurance

Aggregate shock negatively affects the sustainability of the informal risk sharing arrangement, as suggested by results presented in the previous subsections. A natural question to ask is whether access to index insurance will mitigate the hazardous impact brought about by aggregate shocks.

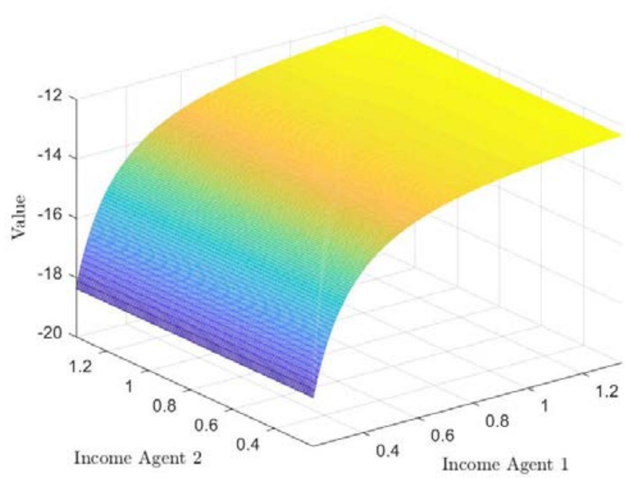


Figure 7: Value Function - With Correlated Income

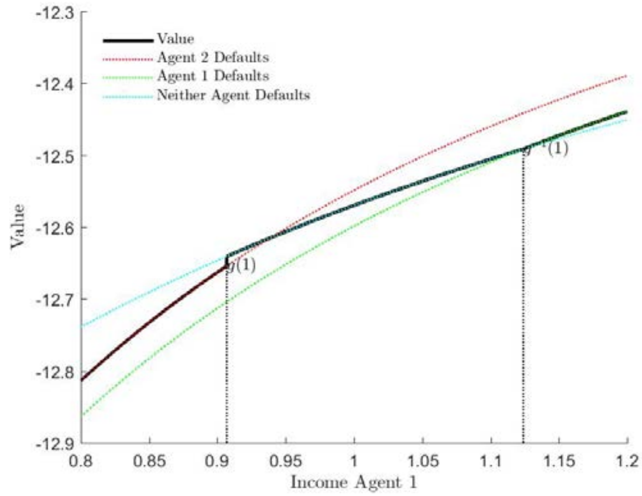


Figure 8: Value Function Projection - With Correlated Income

In contrast to traditional insurance, wherein the indemnity is based on the individual outcome that needs individual verification, index insurance anchors its indemnity payout to an object index, such as precipitation levels, temperature degrees, and the average value of the outcome variable. These indexes are free from moral hazard issues because an individual cannot alter the indexes simply by changing only his or her behavior. Yet these indexes are correlated with individual outcomes in a way that can be relevant to the decision about whether or not to trigger the indemnity payout. Without complicating the model, we assume that index insurance is purchased in every period. Whenever the aggregate level shock occurs, the payout of the amount *l*cover* is made to the agent, where *l* is the amount of loss in the event of drought and $cover \in [0,1]$ is the coverage by the insurance. Note that the indemnity payout is determined by the realization only of the aggregate shock Y. The premium is $\pi = \lambda lp * cover$, where λ is the premium loading, it refers to subsidies when it is lower than 1, to administrative loading when it is greater than 1, and to the actuarially fair case when it is equal to 1. In short, with the access to index insurance, $y_{it} = Y'\varepsilon_{it}$, where,

$$Y' = \begin{cases} Y, & \text{with probability } 1 - p \\ Y + l * cover, & \text{with probability } p \end{cases}$$

We discuss three scenarios in which there is access to index insurance.

Current Period, Only Agent 1 Buys Index Insurance

In the first scenario, access to index insurance is available to only one agent, say, agent 1, during the current period. Let B_{OPOA} be the expected maximum value of being in the risk sharing arrangement for agent 1, discounted by one period. OPOA (One Period One Agent) denotes one-period access to index insurance for only one agent. Then, $B_{OPOA} = \delta E_{\tilde{y}_1', \tilde{y}_2} V(\tilde{y}_1', \tilde{y}_2 | B)$, where $\tilde{y}'_1$denotes the income for agent 1 after the indemnity payout is incorporated. B is the expected maximum value of staying in the risk sharing arrangement without access to index insurance. B_{OPOA} can be calculated iteratively, as suggested in section 1.3. We can calculate the willingness to pay for one-period access to index insurance as follows: $u(1-\pi-WTP_{OPOA})+\delta B_{OPOA}=u(1)+\delta B$, which states the agent is indifferent between buying the insurance and not buying.

Current Period, Both Agents Buy Index Insurance

In the second scenario access to index insurance is available to both agents, but only for the current period. Let B_{OPBA} be the expected maximum value of being in the risk sharing arrangement for agent 1, discounted by one period. OPBA (One Period Both Agents) denotes a one-period access to index insurance for both agents. $B_{OPBA}=\delta E_{\tilde{y}_1',\tilde{y}_2'}V(\tilde{y}_1',\tilde{y}_2'|B)$, where $\tilde{y}_i'$ denotes income for agent *i* after the indemnity payout is incorporated. B is the expected maximum value of staying in the risk sharing arrangement without access to index insurance. B_{OPBA} can be calculated iteratively, as suggested in section 1.3.1. We can calculate the willingness to pay for one-period access to index insurance as follows: $u(1-\pi-WTP_{OPBA})+\delta B_{OPBA}=u(1)+\delta B$.

All Periods, Both Agents Buy Index Insurance

In the last scenario access to index insurance is available to both agents during all periods.

$$B_{APBA}=\delta E_{\tilde{y}_1',\tilde{y}_2'}V(\tilde{y}_1',\tilde{y}_2'|B_{APBA})$$

$\tilde{y}_i'$ denotes income for agent *i* after the indemnity payout is incorporated. B_{APBA} can be calculated in an iterative fashion, as suggested in section 3.1. APBA (All Periods Both Agents) denotes all-period access to index insurance for both agents. We can calculate the willingness to pay for one-period access to index insurance as follows: $u(1-\pi-WTP_{APBA})+\delta B_{APBA}=u(1)+\delta B$.

Table 1: Simulation Results, High Correlation (0.8)

Scenario	Uninsured	OPOA	OPBA	APBA
Availability of Index Insurance	none	one period only	one period only	all periods
Who Buys Insurance	none	agent 1	both agents	both agents
Autarky Utility	-11.88	-11.43	-11.43	-6.85
Utility of Risk Sharing	-11.90	-11.45	-11.45	-6.78
Net Value of Risk Sharing	-0.02	-0.02	-0.02	0.08
Probability of Deviating - Unconditional	0.62	0.63	0.50	0.00
Probability of Deviating - No Drought	0.57	0.57	0.57	0.00
Probability of Deviating - Drought Insured		1.00	0.05	0.00
Probability of Deviating - Drought Uninsured	0.93			
Willingness to Pay for Index Insurance		0.20	0.20	-0.24

Table 2: Simulation Results, Low Correlation (0.0)

Scenario	Uninsured	OPOA	OPBA	APBA
Availability of Index Insurance	none	one period only	one period only	all periods
Who Buys Insurance	none	agent 1	both agents	both agents
Autarky Utility	-9.20	-9.06	-9.06	-7.60
Utility of Risk Sharing	-8.60	-8.50	-8.47	-7.20
Net Value of Risk Sharing	0.61	0.56	0.59	0.40
Probability of Deviating - Unconditional	0.00	0.00	0.00	0.00
Probability of Deviating - No Drought	0.00	0.00	0.00	0.00
Probability of Deviating - Drought Insured		0.00	0.00	0.00
Probability of Deviating - Drought Uninsured	0.00			
Willingness to Pay for Index Insurance		-0.01	0.02	-0.47

Table 1 shows the simulation results for these three insurance scenarios. For comparison, column (1) presents the simulation results when there is no insurance. In panel A, I present the results when their income is highly correlated in these scenarios. When no insurance is available during any period for either agent, as shown in column (1), the maximum expected utility of staying at an informal risk sharing arrangement is -11.903, which is lower than that, -11.882, in autarky. This leads to a negative net expected maximum value of risk sharing: 11.903-(-11.882) = -0.021. It is striking that in the high correlation case, even when no drought occurs in current period, the probability of deviating is a high value of 0.568. This implies that when agents internalize future utility (or disutility) associated with staying the informal risk sharing, they are highly likely to deviate in current period (56.8%), even if drought does not occur currently. When drought occurs and the drought is not insured, the probability of deviating rises to 0.931. The unconditional probability of deviating is (1-*p*)*0.568+*p**0.931=0.62. In column (2) I present the results when only agent 1 has access to a one-period indemnity payout (current period). The expected utility in autarky increases a little compared to the scenario in which no insurance indemnity is available. However, for agent 1 the expected maximum utility of staying in an informal risk sharing arrangement is still lower than that of staying in autarky. This can be attributed to the fact that agent 2 has no access to an index insurance indemnity payout during the current period. This, in turn, leads to more risk sharing responsibility for agent 1 because after the indemnity payout, agent 1's income is more likely to be higher than agent 2's income[9]. Having access to one-period insurance indemnity does not agent 2 prefer making informal risk sharing more favorable to than staying in autarky. The net value of risk sharing remains below zero. The probability of deviating conditional on there being no drought is still 0.568. However, the probability of deviating conditional on drought occurring during the current period rises to 1 for agent 1. This is because in the current period, agent 1 has access to insurance indemnity and this indemnity payout is also transferable. Thus, agent 1's incentive to stay in the informal risk sharing is reduced by agent 1's

[9] In this chapter, indemnity payout is counted as transferable income.

access to the indemnity payout. The unconditional probability of deviating is (1-*p*) *0.568+*p* *1= 0.63 during the period when agent 1 has access to indemnity payout. The willingness to pay for access to this one-period indemnity payout can be calculated by $u(1-\pi-\mathrm{WTP}_{\mathrm{OPOA}})+\delta\mathrm{B}_{\mathrm{OPOA}}=u(1)+\delta\mathrm{B}_0$, where $\mathrm{B}_{\mathrm{OPOA}}$ and B_0 refer to the expected value of risk sharing in One-Period-One-Agent insurance and in no insurance, respectively. In this case, the $\mathrm{WTP}_{\mathrm{OPOA}}$ is 0.202.

In column (3) we present the results when both agents have access to a one-period indemnity payout. The expected value for agent 1 of staying in informal risk sharing increases by a small margin compared to the OPOA scenario. This is intuitive. Agent 1's utility is improved when agent 2 also gets paid in the case of drought. However, the net value of informal risk sharing is still below zero. When a drought occurs and both agents are insured, the probability of deviating reduces to 0.053, as opposed to 1 in the OPOA case. However, this probability applies only to that period when the insurance indemnity payout is available. The unconditional probability of deviating, (1-*p*)*0.568+*p**0.053, decreases from 0.63 in the OPOA case to 0.495 in the OPBA case. During the following period, the probability of deviating returns to 0.62 because no insurance is available during the other periods. The expected number of periods during which this informal risk sharing arrangement is maintained is less than 1/0.495=2.02. The willingness to pay for access to this OPBA payout can be calculated by $u(1-\pi-\mathrm{WTP}_{\mathrm{OPBA}})+\delta\mathrm{B}_{\mathrm{OPBA}}=u(1)+\delta\mathrm{B}_0$, where $\mathrm{B}_{\mathrm{OPBA}}$ and B_0 refer to the expected value of risk sharing in One-Period-Both-Agents insurance and in no insurance, respectively. The $\mathrm{WTP}_{\mathrm{OPBA}}$, in this case, is 0.203, which is slightly higher than $\mathrm{WTP}_{\mathrm{OPOA}}$.

In column (4), we present the results when both agents have access to the indemnity payout during all periods (All-Period-Both-Agents). Because during all periods the loss from drought is covered by insurance, the value of staying in autarky, -6.854, increases by a large margin. For the first time in the three insurance scenarios considered, the value of informal risk sharing exceeds the value of staying in autarky, which gives the informal risk sharing arrangement a positive net value. The probability of deviating is numerically zero in all scenarios (i.e., in the no-drought, insured-drought, and unconditionally scenarios). The one-time $\mathrm{WTP}_{\mathrm{APBA}}$, however, is negative. This suggests that policymakers need to either develop a payment plan that follows a reasonable schedule or offer subsidies to this one-time payment.

Comparing the OPOA, OPBA, and APBA cases, we conclude that continuously insuring against the drought loss helps to improve the sustainability of informal risk sharing arrangement. A one-time indemnity payout cannot improve informal risk sharing; instead, the payout damages risk sharing, especially if the insurance is available to only one agent in the arrangement. Making insurance available to both agents will support the informal risk sharing in the case of one-time insurance and greatly in the case of continued insurance coverage. But insurance practitioners need to cooperate with the customers to develop a dynamic and re-occurring plan to collect the premiums. Otherwise, subsidies are needed for continued insurance.

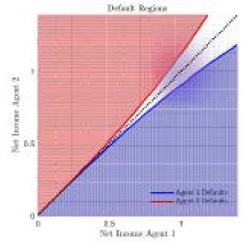
In panel B, we present the results when income levels of agents are lowly correlated. In column (1) to column (4), we present the baseline results when no insurance, OPOA insurance, OPBA insurance, and APBA insurance is available, respectively. In all cases, the net value of the informal risk sharing arrangement is positive. However, the net value of informal risk sharing is highest when no insurance is available, and it is lowest when insurance is available in all periods. This suggests that when the income of agents is lowly correlated, index insurance and informal risk sharing compete as risk-management channels for agents. There are substitution effects between index insurance and informal risk sharing in the low correlation case. In all cases, the probability of deviating, both unconditionally and conditionally, is unanimously zero. The WTP is negative for both the OPOA and the APBA cases.

Deviating Region

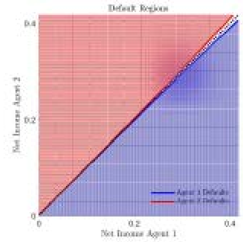
In Figure 9 we present the deviating region when agents' income levels are highly correlated. Four cases are analyzed in detail: no insurance, OPOA insurance, OPBA insurance, and APBA insurance.

The left panel in Figure 9 presents the deviating region conditional on there being no drought in a period; the right panel presents the deviating region conditional on drought occurring in a period. Subfigures (a) and (b) denote the case when no insurance is available. When their income distributions fall into the blue- and red- shaded area, the risk sharing arrangement collapses, and either agent 1 or agent 2 deviates. The light purple-shaded area plots the realization of simulated income for both agents. The deviating probability can be approximated by the region in which the purple-shaded area intersects with the blue- and red-shaded area. Comparing subfigures (b) and (a), when drought occurs the deviating probability increases from 0.568 to 0.931 (from Table 1).

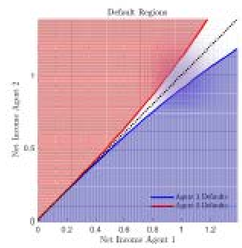
When a one-period insurance indemnity payout is available only to agent 1 (OPOA insurance), access to insurance does not help; instead, when drought does occur in the current period, the payout exacerbates the incentive for agent 1 to deviate. The access to the indemnity payout (of the amount *l*coverage* = 0.1) for agent 1 causes agent 1 to deviate (see subfigure (d)). The 45-degree line in subfigure (d) moves parallel and upwards by an amount of 0.7 compared to that in subfigure (c), showing that only when agent 2's income is 0.7 higher than agent 1's income will agent 2 decide whether to make a transfer. As shown in the light purple region, most of the income realizations lie within agent 1's deviating region.



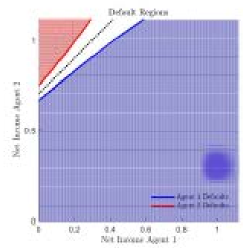
(a) No Insurance - No Drought



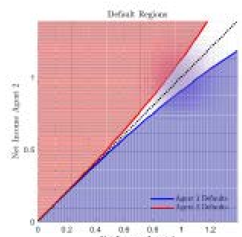
(b) No Insurance - Drought



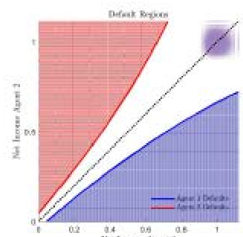
(c) OPOA Insurance - No Drought



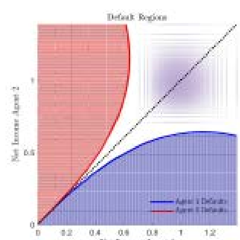
(d) OPOA Insurance - Drought



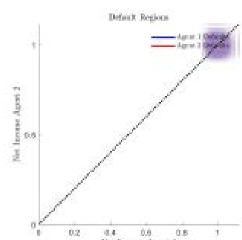
(e) OPBA Insurance - No Drought



(f) OPBA Insurance - Drought



(g) APBA Insurance - No Drought

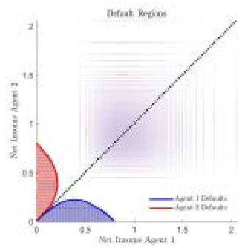


(h) APBA Insurance - Drought

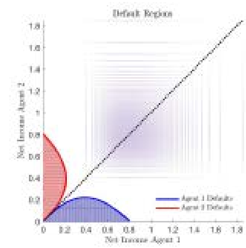
Figure 9: Deviating Region – High Income Correlation

When a one-period insurance indemnity payout is available to both agent 1 and agent 2 (OPBA insurance), the access to insurance reduces the incentive to deviate if a drought occurs. As suggested in subfigure (f), most of the income realizations lie outside the deviating regions of the two agents. However, when drought does not occur in the current period, both agents will be highly incentivized to deviate from the risk sharing arrangement (see subfigure (e)). The incentive to deviate stems from the negative net value of risk sharing. When the insurance indemnity payout is available to both agents (APBA insurance), the incentive to deviate is zero, regardless of whether the drought occurs or not (see subfigure (g) and (h)).

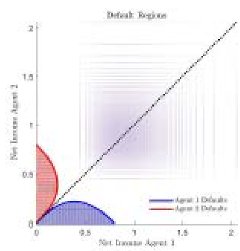
In comparison, we present in Figure 10 the deviating region when the income levels of agents are lowly correlated. When agents' income levels are lowly correlated, the net value of the informal risk sharing arrangement is positive, and the deviating probability is numerically zero in the no insurance, OPOA insurance, OPBA insurance, and APBA insurance scenarios.



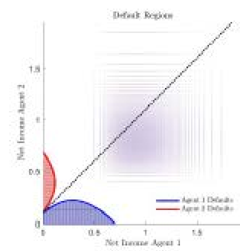
(a) No Insurance - No Drought



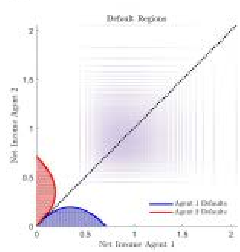
(b) No Insurance - Drought



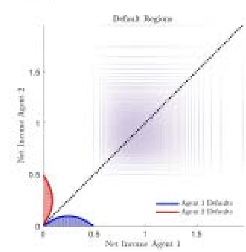
(c) OPOA Insurance - No Drought



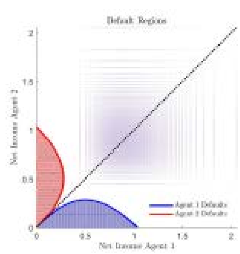
(d) OPOA Insurance - Drought



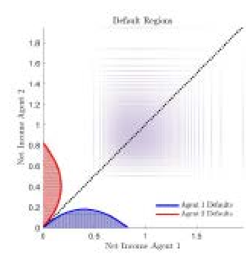
(e) OPBA Insurance - No Drought



(f) OPBA Insurance - Drought



(g) APBA Insurance - No Drought



(h) APBA Insurance - Drought

Figure 10: Deviating Region – Low Income Correlation

5 Sensitivity Analysis

To test the robustness of the results and investigate how the results change as parameters change, we conduct the following sensitivity analysis by changing the drought probability, *p*, the drought severity, *l*, income correlation, *Corri*, income volatility, *Vary*, insurance coverage, *cover*, the degree of relative risk aversion, α, the exogenous risk sharing rate, θ, and the social penalty, γ. We also compare the simulation results in the no-insurance with those in the OPOA-insurance (Figure 11, Figure 14, and Figure 17), the OPBA insurance (Figure 12, Figure 15, and Figure 18), and APBA insurance (Figure 13, Figure 16, and Figure 19) scenarios.

5.1 Net Value of Risk Sharing Arrangement

First, let us focus on the expected value of risk sharing (Figure 11, Figure 12, and Figure 13). In the OPOA scenario, the red line is below the blue line in all subfigures, which indicates that for the agent who has the access, the net value of staying in risk sharing when only he or she has access to index insurance during the next period is lower than the net value of staying in risk sharing when none of the agents have access to index insurance. The net value of informal risk sharing when no access to insurance is available decreases with drought probability, drought severity, and income volatility; and it increases with risk aversion. In contrast, it first decreases, then increases, then decreases with stigma penalty. Subfigure (g) in Figure 11 illustrates how the net value changes as the exogenous informal risk sharing rate changes. In subsection 1.3 and 1.4, the exogenous risk sharing rate is fixed to 1. Subfigure (g) suggests that the optimal level of the exogenous risk sharing, wherein the value of staying in this informal risk sharing arrangement is maximized in OPOA and no-insurance scenarios, is about 0.1.

In the OPBA case (Figure 12), the red line either coincides with the blue line (subfigure (a), (b), part of (c), (g), and (h)) or it is higher than the blue line (subfigure (d), (e), part of (f), (g), (h)). This indicates that the net value of staying in the informal risk sharing arrangement when both agents have access to insurance during the next period is no less than the net value of the informal risk sharing arrangement when no insurance is available. The difference between the red line and the blue line increases dramatically when the coverage increases (subfigure (e)). Even with OPBA insurance, the optimal exogenous risk sharing rate is around 0.1 (see subfigure (g) in Figure 12).

Turning to Figure 13, which illustrates the APBA scenario, the red line is higher than the blue line in subfigure (a), (d), (e), (f), (h), whereas in (b) and (g) it is mostly higher. However, the net value of informal risk sharing still decreases with income correlation, even in the APBA insurance scenario. When income correlation is high (above the 0.5 threshold), the net value in APBA is higher than the net value when no insurance is available. Subfigure (g) indicates that the optimal exogenous risk sharing rate with APBA insurance is 0.7, which is much higher than that when no insurance, OPOA insurance, and OPBA insurance are available. In Figure 11, Figure 12, and Figure 13, the blue line is consistent.

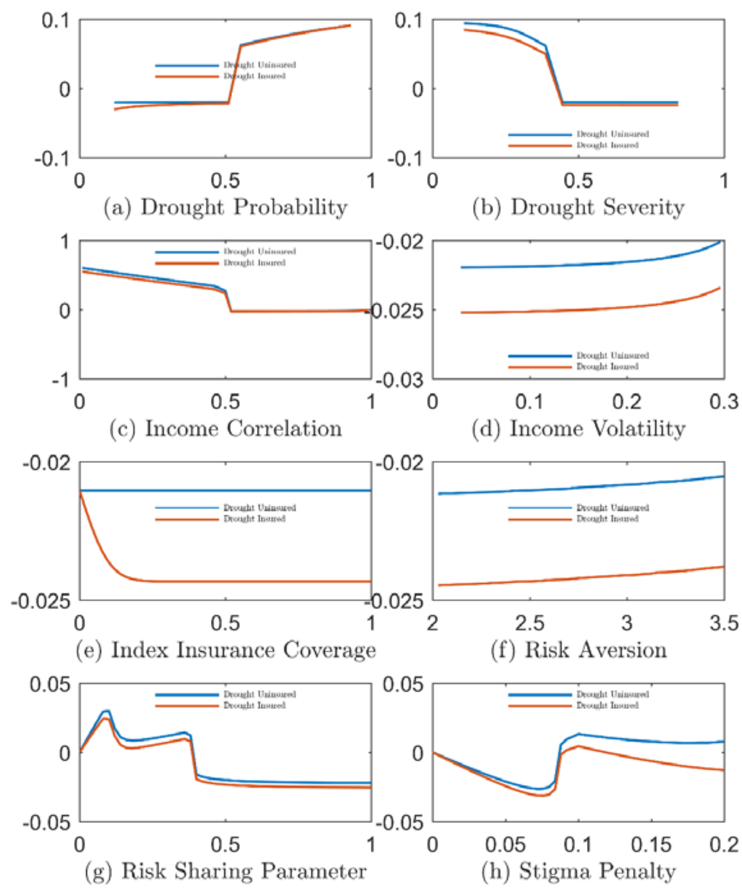


Figure 11: Sensitivity Analysis – Net Value of Risk Sharing – OPOA Insurance

5.2 Deviating Probability

In Figure 14, Figure 15, and Figure 16, we plot the conditional deviating probability for the OPOA insurance, OPBA insurance, and APBA insurance, respectively. In Figure 14, the deviating

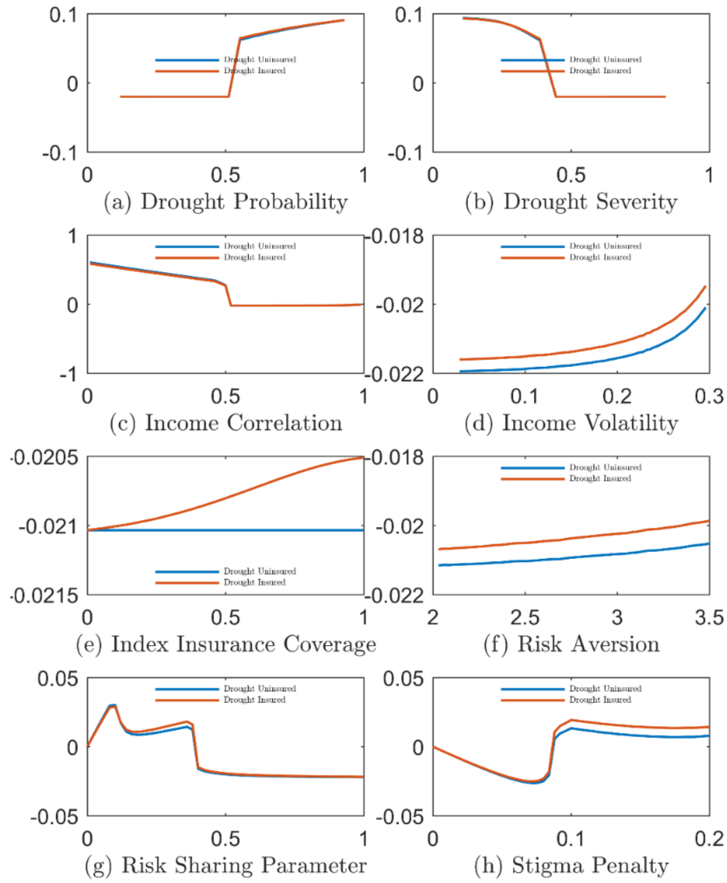


Figure 12: Sensitivity Analysis – Net Value of Risk Sharing – OPBA Insurance

probability, say, for agent 1, during any period, given that in that period, drought occurs and agent 1 has access to the OPOA insurance, is no less than the deviating probability in that period, given that either no drought occurs in that period or drought occurs but no insurance is available for most of the time (Subfigure (g) shows an exception: when the risk sharing rate is lower than 0.16). In subfigure (a), (d), (e), (f), and (h), the probability is constantly 1, irrespective of changes in the parameters (e.g., drought probability, insurance coverage, risk aversion, and stigma penalty). Note that the yellow line is lower than the blue line, meaning that the deviating

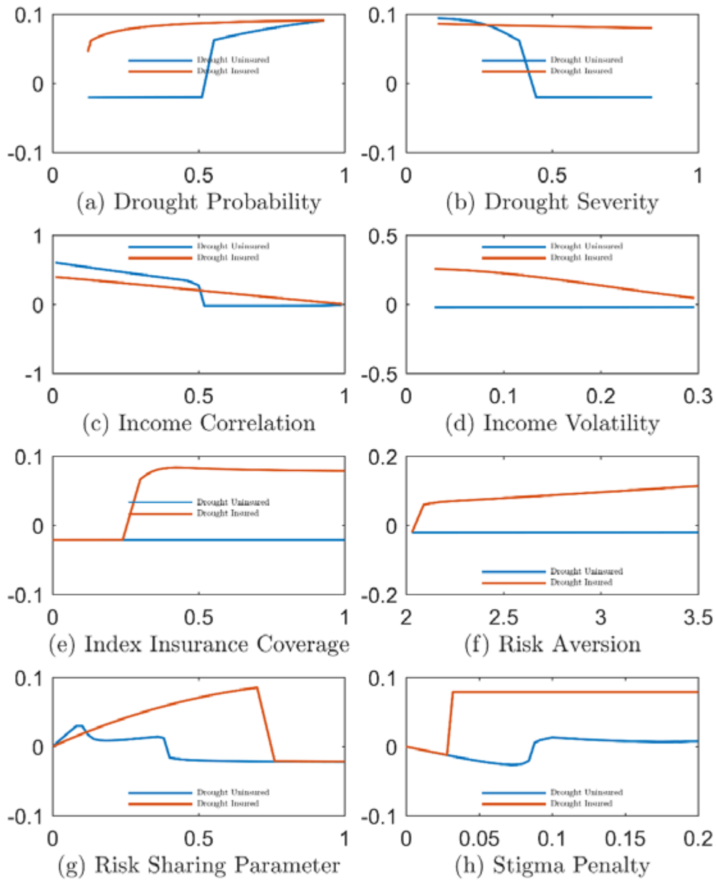


Figure 13: Sensitivity Analysis – Net Value of Risk Sharing – APBA Insurance

probability is lower during a period when no drought occurs than it is during a period when drought occurs, but no insurance is available, which is consistent with intuition. In Figure 15, the yellow line remains below the blue line, but because insurance is available to both agents, the red line, too, is below the yellow line (except in subfigure (e), which illustrates the insurance coverage case). In a drought situation the deviating probability is reduced by the availability of the OPBA insurance to a level that is even lower than the deviating probability in a non-drought

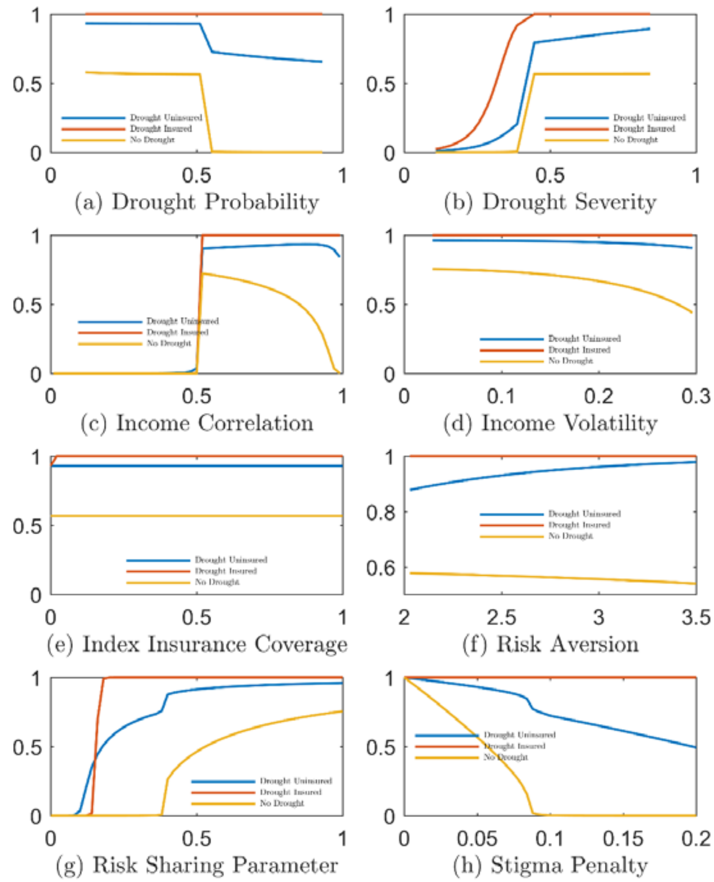


Figure 14: Sensitivity Analysis – Probability of Deviating – OPOA Insurance

situation. The deviating probability in a drought situation that includes access to OPBA insurance decreases with insurance coverage (subfigure (e)) and social stigma (subfigure (h)) and increases with the exogenous risk sharing rate (subfigure (g)). When the income-correlation coefficient is higher than 0.5, the deviating probability in a drought and in the OPBA scenario decreases with the income correlation, whereas probability in a drought and in a no-insurance situation the deviating remains around 0.9.

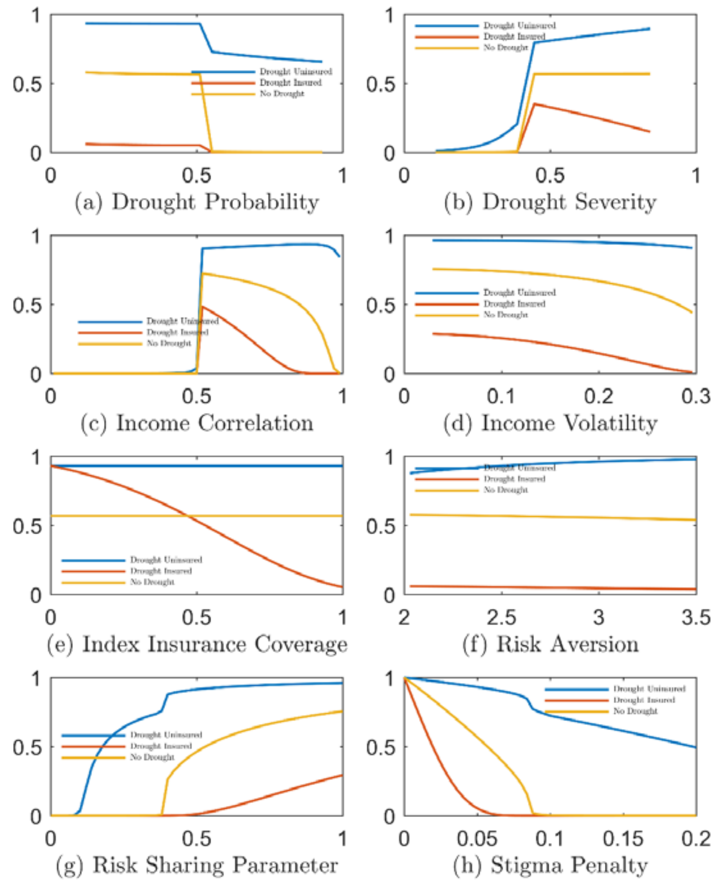


Figure 15: Sensitivity Analysis – Probability of Deviating – OPBA Insurance

Figure 16 shows the result when the insurance is changed to the APBA type: as shown in the figures just discussed, the blue line remains unchanged. However, both the yellow and red line are reduced significantly — almost to 0 — as illustrated in subfigures (a), (b), (c), and (f). (In these subfigures the yellow line covers the red line, making the appearance that the red line is missing.). When insurance coverage is higher than 0.4, or the exogenous risk sharing rate is lower than 0.7, or the social penalty is higher than 0.003; the deviating probability given by the red and yellow line achieves 0. It is striking that having access to APBA insurance reduces the

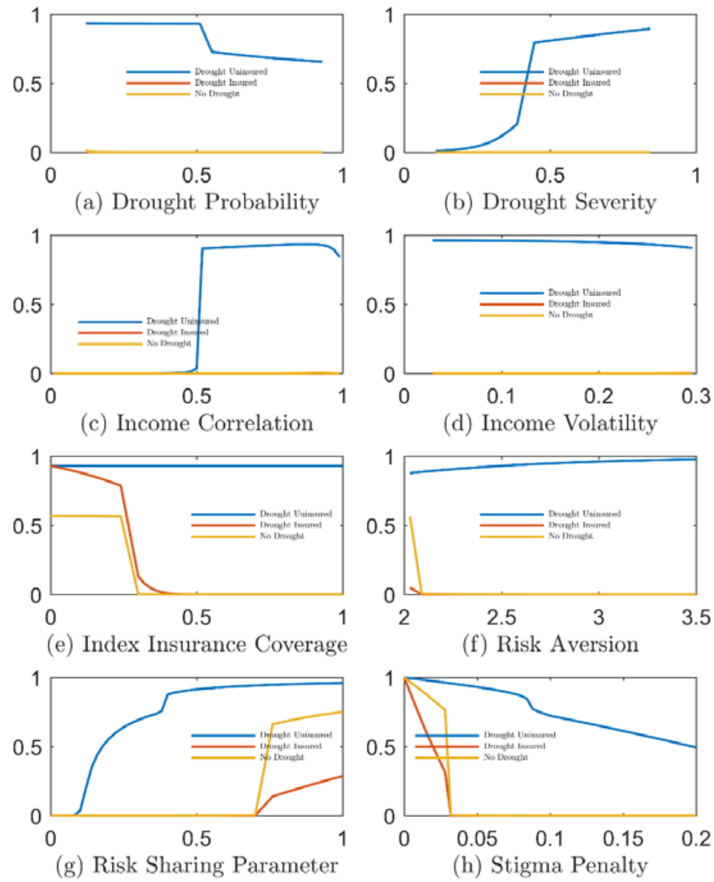


Figure 16: Sensitivity Analysis – Probability of Deviating – APBA Insurance

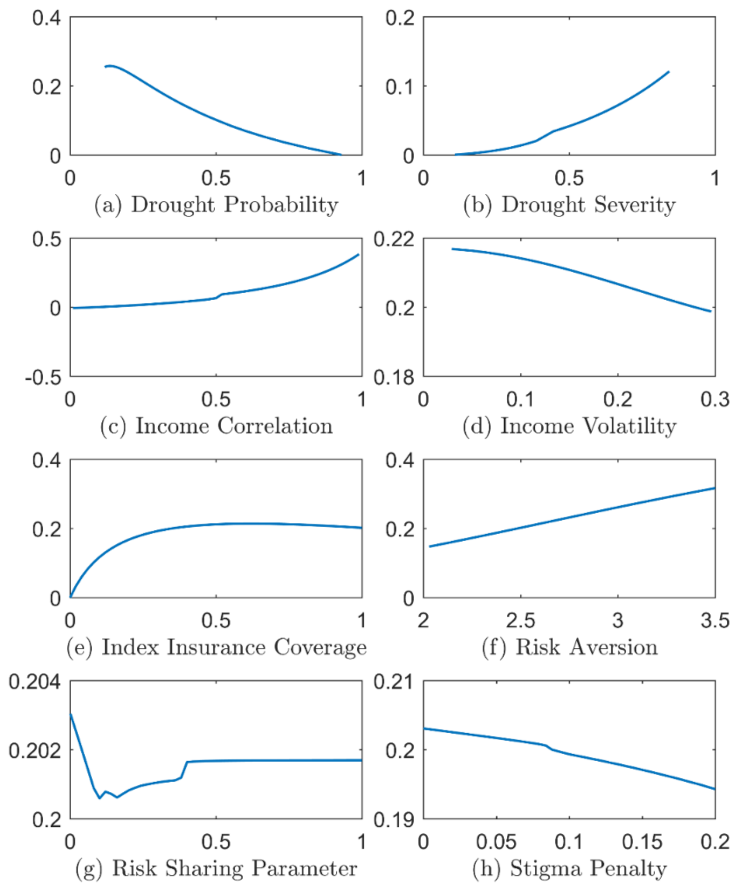


Figure 17: Sensitivity Analysis – Willingness to Pay – OPOA Insurance

deviating probability in both drought and non-drought situations, which is not true in the case of OPBA and OPOA insurance. The income correlation does not affect the deviating probability in a drought or in the APBA insurance case, as the probability is constantly 0 as the correlation coefficient increases.

The blue line is the same across Figure 14, Figure 15, and Figure 16. The deviating probability in uninsured drought situation increases with drought severity, income correlation, risk aversion, and the exogenous risk sharing rate. It decreases with stigma penalty, and it roughly decreases with income volatility.

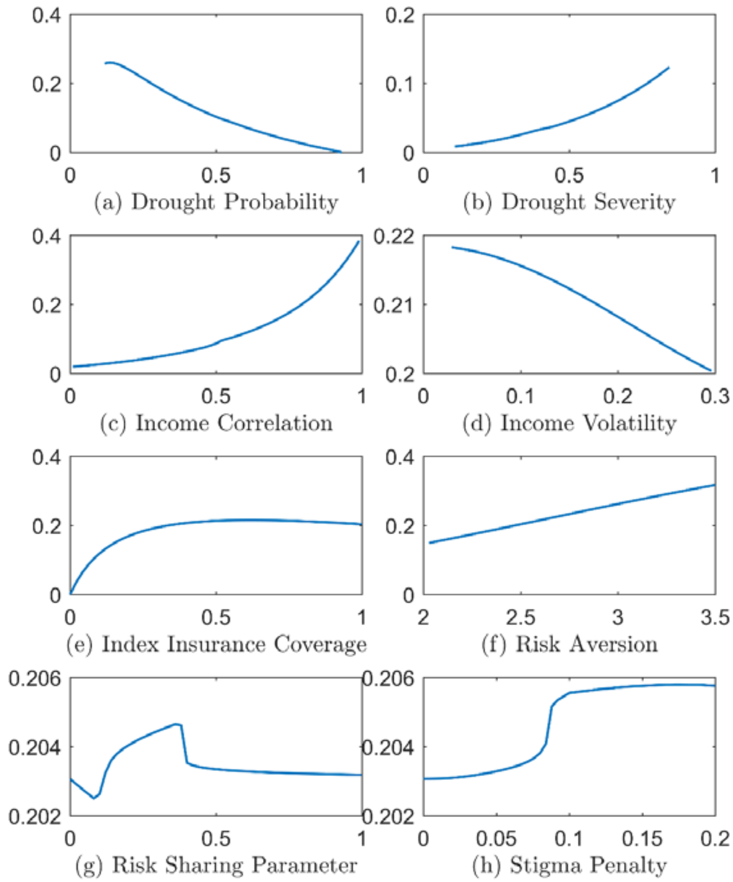


Figure 18: Sensitivity Analysis – Willingness to Pay – OPBA Insurance

5.3 Willingness to Pay

The analysis for willingness to pay is presented in Figure 17, Figure 18, and Figure 19. In the case of OPOA and OPBA insurance, willingness to pay is positive and it increases with all parameters except the exogenous risk sharing rate. In the case of APBA insurance, the willingness to pay is negative in most cases. It increases with income correlation and income volatility, and with the exception of the exogenous risk sharing rate, it decreases with drought probability, drought severity, insurance coverage, and risk aversion parameters.

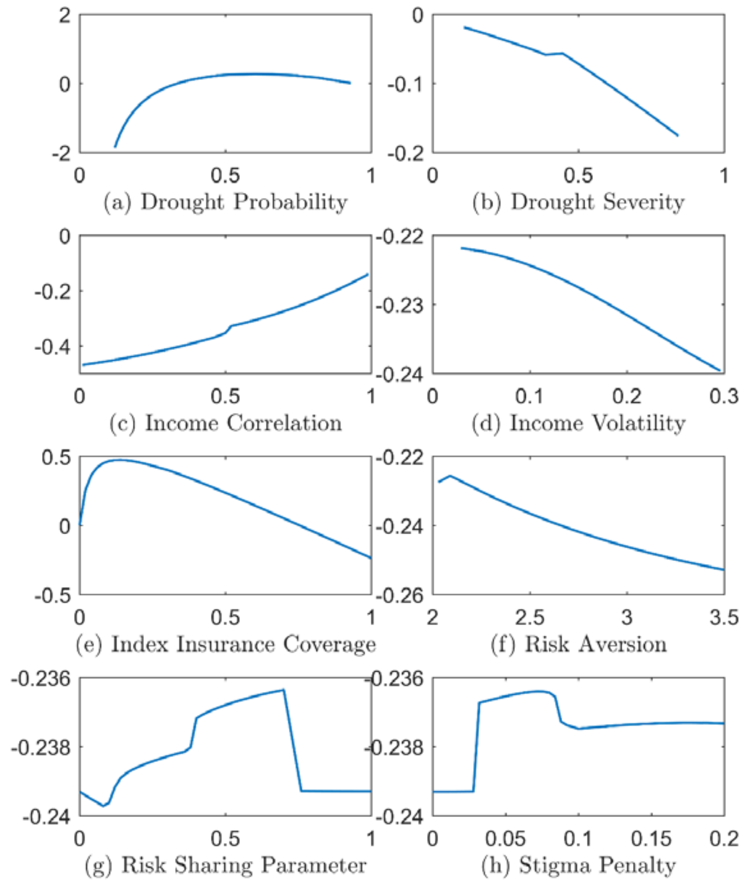


Figure 19: Sensitivity Analysis – Willingness to Pay – APBA Insurance

6 Conclusions and Implications

The informal risk sharing arrangement is prevalent in developing countries, yet the sustainability of such arrangements hinges on the coverage against aggregate-level shocks. To the best of our knowledge, this is the first paper to examine the sustainability of the informal risk sharing arrangement that includes the presence of aggregate shocks. Moreover, we have considered how the introduction of formal insurance, such as index insurance, improves the plight of informal risk sharing associated with aggregate shocks. We have found that when agents' income levels become correlated due to the aggregate level shocks, the net value of staying in the informal risk sharing arrangement becomes negative and the deviating probability hits a high value of 0.931. In comparison, when agents' income levels are almost non-correlated, the net value of staying in the informal risk sharing arrangement becomes positive and the deviating probability is 0.

We introduce index insurance into the informal risk sharing arrangements. We considered three schemes of index insurance: (1) One-Period-One-Agent (OPOA) insurance; (2) One-Period-Both-Agent (OPBA) insurance; (3) All-Period-Both-Agent (APBA) insurance. We find that in the OPOA scenario, when only one agent purchases index insurance, the fact that only one agent has access to the insurance payout renders the informal risk sharing arrangement less sustainable (in terms of the negative net value of informal risk sharing and the elevated deviating probability) than in the no-insurance case. When both agents buy index insurance during the current period, the deviating probability, which is conditional on drought, can fall. However, the deviating probability that is conditional on no drought continues to have a high value. When both agents purchase index insurance during all periods, the net value of informal risk sharing becomes positive. The unconditional and conditional deviating probability becomes zero. Sensitivity analysis confirms our results.

This work has important implications for current pilot projects that promote index insurance and that aim to improve the financial environment in developing countries. Our results suggest that for it to take effect, an insurance product needs a long-term plan. One-Time access to index insurance payout often impedes rather than enhances in-place informal insurance. Building a long-term, reliable, and trustworthy insurance project with local farmers and pastoralists can help solidify the extant informal risk sharing arrangements that help participants cope with aggregate-level shocks that make people's income correlated. It also is important to develop a sound installment payment plan because judging from our results, it is unrealistic to ask people to make a one-time purchase of lifelong insurance.

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Appendix A: Calculation of Variance

Given the mean of y_i, Mean, the variance of y_i, Vary, and the correlation coefficient between income levels of agent 1 and agent 2, Corri, We can determine the loss of drought, l, the probability of drought, p, and the variance of idiosyncratic log-income, σ^2. First, we have:

$$\mathrm{E(Y)} = 1 - lp,\ \mathrm{var(Y)} = l^2 p(1-p),$$

$$\mathrm{E}(\varepsilon_i) = 1,\ \mathrm{var}(\varepsilon_i) = \exp(\sigma^2) - 1,$$

$$\mathrm{E}(y_i) = \mathrm{E}(\mathrm{Y}\varepsilon_i) = \mathrm{E(Y)} = 1 - lp,$$

$$\begin{aligned}\mathrm{var}(y_t) = \mathrm{var}(\mathrm{Y}\varepsilon_i) &= \mathrm{var(Y)}\mathrm{var}(\varepsilon_i) + \mathrm{var(Y)}\big(\mathrm{E}(\varepsilon_i)\big)^2 + \mathrm{var}(\varepsilon_i)\big(\mathrm{E(Y)}\big)^2 \\ &= l^2(p-p^2)(\exp(\sigma^2)-1) + l^2(p-p^2) + (\exp(\sigma^2)-1)(1-lp)^2 \\ &= (\exp(\sigma^2)-1)(l^2p+1-2lp) + (l^2p - l^2p^2)\end{aligned}$$

$$\mathrm{cov}(y_1, y_2) = \mathrm{E}[(y_1 - 1 + lp)(y_2 - 1 + lp)] = l^2p - l^2p^2$$

as,

$$\mathrm{cov}(y_1, y_2) = \mathrm{Vary} * \mathrm{Corri}$$

and,

$$\mathrm{Mean} = 1 - lp$$

so,

$$(1 - \mathrm{Mean}) * l - (1 - \mathrm{Mean})^2 = \mathrm{Vary} * \mathrm{Corri}$$

$$l = \frac{\mathrm{Vary} * \mathrm{Corri} + (1 - \mathrm{Mean})^2}{1 - \mathrm{Mean}}$$

$$\mathrm{p} = \frac{(1 - \mathrm{Mean})^2}{\mathrm{Vary} * \mathrm{Corri} + (1 - \mathrm{Mean})^2}$$

$$\sigma^2 = \log\Big(\frac{\mathrm{Vary} - (l^2p - l^2p^2)}{l^2p + 1 - 2lp} + 1\Big)$$

Appendix B. Convergence of the Slope in the Fixed-Point

Only consider the no-insurance case, $B_{n+1} = \delta E(V(y_1, y_2, A, B_n))$.

When B is high, then the agent never deviates,

$$\begin{aligned} E(V(y_1, y_2, A, B)) &= E(u(y_1 - 0.5\theta(y_1 - y_2))) + B \\ &= E(u((1 - 0.5\theta)y_1 + 0.5\theta y_2)) + B \end{aligned}$$

Multiply both sides by δ , so,

$$B_{n+1} = \delta E(u((1 - 0.5\theta)y_1 + 0.5\theta y_2)) + \delta B_n.$$

So, when B is high, the slope of the fixed-point map is δ.

When B is low, then the agent deviates,

$$V(y_1, y_2, A, B) = u(y_1) + A - 0.5\gamma,$$

so,

$$E(V(y_1, y_2, A, B)) = E(u(y_1)) + A - 0.5\gamma\ ,$$

multiply both sides by δ, so,

$$\delta E(V(y_1, y_2, A, B)) = \delta E(u(y_1)) + \delta A - 0.5\delta\gamma,$$

so,

$$B_{n+1} = \delta E\big(u(y_1)\big) + \delta A - 0.5\delta\gamma$$

Substitute $A = \frac{E(u(y_i))}{1-\delta}$into the equation. We get $B_{n+1} = A - \frac{\delta\gamma}{2}$. So, when B is low, the slope of the fixed-point map is 0. Appendix C. Idiosyncratic Income and Loss

In this paper, section 1.4.1.1, we assume $y_i = Y\varepsilon_i$. Y denotes the aggregate shock which is common to both agents. Y follows the following distribution:

$$Y = \begin{cases} 1, & \text{with probability } 1 - p \\ 1 - l, & \text{with probability } p \end{cases}$$

ε_i denotes the idiosyncratic shock for agent *i*. It follows a log-normal distribution with a mean of $-0.5\sigma^2$, and a variance of σ^2. It is easy to see that $E(\varepsilon_i) = \exp(-0.5\sigma^2 + 0.5\sigma^2) = 1$. So,

$$E(y_{it}) = \begin{cases} 1, & \text{with probability } 1 - p \\ 1 - l, & \text{with probability } p \end{cases}$$

It is easy to prove that it makes no difference to assume that,

$$y_{it} = \begin{cases} \eta_{it}, & \text{with probability } 1 - p \\ \xi_{it}, & \text{with probability } p \end{cases}$$

where η_i follows a log-normal distribution with a mean of $\log(1) - 0.5\sigma^2$, and a variance of σ^2. ξ_i follows a log-normal distribution with a mean of $\log(1 - l) - 0.5\sigma^2$ and a variance of σ^2. It is easy to see that $E(\eta_i) = \exp(\log(1) - 0.5\sigma^2 + 0.5\sigma^2) = 1$ and $E(\xi_i) = \exp(\log(1 - l) - 0.5\sigma^2 + 0.5\sigma^2) = 1 - l$. We used this trick in the simulation process.